ABRASIVE WEAR OF FOUR DIRECT RESTORATIVE MATERIALS BY STANDARD AND WHITENING DENTIFRICES

by

Gregory M. Gittleman
Lieutenant, Dental Corps, U.S. Navy

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CERTIFICATE OF APPROVAL

MASTER'S THESIS

This is to certify that the Master's thesis of

Gregory M. Gittleman
Lieutenant, Dental Corps, U.S. Navy

has been approved by the Examining Committee for the thesis requirement for the Master of Science degree in Oral Biology at the June 2013 graduation.

Thesis Committee:

Kim E. Diefenderfer, DMD, MS, MS
CAPT, DC, USN
Professor, Dental Research Department

Joseph D. Molinaro, DMD, MS
CAPT, DC, USN
Graduate Program Director, Comprehensive Dentistry

Michael E. Rudmann, DMD, MS
CDR, DC, USN
Associate Professor, Comprehensive Dentistry

Glen A. Munro, DDS, MBA
Dean
Naval Postgraduate Dental School

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Gregory M. Gittleman

Gregory M. Gittleman
Comprehensive Dentistry Graduate Program
Naval Postgraduate Dental School
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ABSTRACT

ABRASIVE WEAR OF FOUR DIRECT RESTORATIVE MATERIALS

BY STANDARD AND WHITENING DENTIFRICES

GREGORY M. GITTLEMAN
MS, COMPREHENSIVE DENTISTRY DEPARTMENT, 2013

Thesis directed by: CAPT Kim E. Diefenderfer, DC, USN
Professor, Dental Research Department
Naval Postgraduate Dental School

Introduction: Tooth brushing with dentifrice is the most commonly practiced oral hygiene procedure in developed countries.. Abrasives, such as calcium carbonate and hydrated silica, are incorporated into dentifrices to remove food debris and superficial stains. Insufficient abrasiveness promotes the formation of pellicle and increased bacterial adhesion. Whitening toothpastes generally contain harsher abrasives and remove extrinsic stain more effectively than standard toothpastes. However, increased abrasiveness may damage enamel and dentin, as well as restorative materials used for cervical lesions. Moreover, restorative materials may vary in abrasion resistance. New materials must be evaluated to determine their resistance to dentifrice-induced abrasion.

PURPOSE: To determine the effects of a standard and a whitening dentifrice on the abrasion resistance and surface topography of four esthetic restorative materials commonly used to treat cervical lesions.

METHODS: Four restorative materials (resin composite, glass ionomer, resin-modified glass ionomer, and giomer) were selected. Twenty-seven specimens (5 mm diameter x 3 mm high) per material were fabricated and stored in deionized water. Specimens were brushed in a toothbrushing simulator (200 gm load; 150,000 strokes) using a standard or whitening dentifrice, or distilled water. The mass of each specimen was measured at baseline, 50,000, 100,000, and 150,000 strokes. For each treatment group, mean (± S.D)

masses were compared via Repeated Measures ANOVA. Representative specimens were viewed microscopically (600X) at each interval to assess surface topography.

RESULTS: All materials exhibited slight, but statistically significant decreases in mass from baseline through 150,000 strokes (all $p < 0.04$). For each material, standard and whitening dentifrices and deionized water produced no significant differences in mass loss (all $p > 0.225$). For each abrasive medium, and for all three media combined, the order of mass loss was as follows: resin composite (0.31%) $<$ giomer (0.78%) $<$ resin-modified glass ionomer (1.23%) $<$ glass ionomer (1.43%). Mass loss was significantly greater for the glass ionomer than for the resin and the giomer. Surface topography appeared relatively unchanged for each material from baseline through 150,000 strokes.

CONCLUSIONS: Standard and whitening dentifrices exhibited minimal abrasiveness against four restorative materials. Abrasion resistance was clinically acceptable for all materials.

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CHAPTER I: REVIEW OF THE LITERATURE

A dentifrice is a preparation (paste, powder, cake, or liquid), which aids in the removal of debris from tooth surfaces (Davis, 1978). The first forms of dentifrices date back over 2000 years ago with Hippocrates describing use of calcium carbonate as an abrasive. Toothbrushing with toothpaste is the most commonly practiced oral hygiene procedure in developed countries (Frandsen, 1986). The main physically active ingredient in dentifrices is the abrasive. The abrasive has varied greatly throughout history and today, often changing formulation, as well as size (Davis, 1978; White, 2001; Joiner, 2007).

The purpose of the abrasive is to mechanically remove debris and deposits from the tooth surface, namely: food debris, plaque, acquired pellicle (a proteinaceous film), and calculus. A study by McCauley and colleagues (1946) explored the efficacy of various abrasives in dentifrices. They found that an insufficiently abrasive dentifrice favors the production of a pigmented pellicle.   Similarly, Saxton (1976) confirmed that an abrasive is necessary to control the thickness of pellicle and to prevent the accumulation of cosmetic stain. In addition, he found that during the maturation of the pellicle, it became more adherent and more difficult to remove. However, while insufficient abrasiveness can promote the formation of pellicle and increased bacterial adhesion, excessive abrasiveness is detrimental as well. Certain physical characteristics of the abrasive particles, such as hardness, acuteness or particle sharpness, shape, size, and ductility, have been shown to have a pronounced effect on their ability to wear surfaces (Turssi, Purquerio, and Serra, 2003).

ABRASION OF TOOTH STRUCTURE

Hard tissue abrasion is a familiar consequence of toothbrushing. Enamel, dentin, and cementum differ in their hardness and susceptibility to wear. Most of the current studies show that toothpastes have little effect on enamel, but have a more dramatic effect on dentin (Vicentini, Braga, and Sobral, 2007; Addy, 2005; Sangnes, 1976; Wiegand and colleagues, 2009). The effect of toothbrush abrasion on creating cervical lesions and altering tooth surface is an area of interest in the dental community. This has led to the development of a number of methods to better evaluate these effects. The two parameters most often measured are abrasiveness and surface roughness. International Organization of Standardization (ISO) developed standardized methods for measuring the abrasion of tooth structure by toothpastes. ISO Standard 11609 (1995) quantifies the abrasiveness of a material (e.g. dentifrice) by its relative dentin abrasion (RDA) and relative enamel abrasion (REA). These values are determined by the ability of the toothpaste to remove radioactive dentin or enamel under standardized testing conditions. In this system, on a scale from 0 to100, a higher RDA or REA value indicates a greater abrasive formula. The RDA value is a good measure of the relative abrasiveness of a dentifrice, as compared to other dentifrices; this gives an estimate of how much of the surface is abraded in relative terms, but not in absolute numbers. The roughness of the surface can be measured using surface profilometry and is reported as a surface roughness value (Ra-value) (Liljeborg, Tellefsen, and Johannsen, 2010).

Several studies have examined the effects of dentifrices on hard tooth structure. An *in situ* study by Addy and colleagues (2002) found that toothbrushing with toothpastes does abrade dentin, and the wear shows a reasonable correlation to the

toothpastes' RDA values. Wiegand and colleagues (2009) found that abrasion of exposed dentin was influenced mainly by the abrasivity of the toothpaste and, to a lesser extent, by the hardness of the toothbrush. They also found that the abrasivity had a greater effect than toothbrush filament diameter.

This is not to say that the abrasive in a dentifrice is the sole factor determining abrasion. Numerous factors associated with the toothbrush itself, such as type of brush, filament stiffness, filament end-rounding, and filament orientation, may play a role in abrasion (Wiegand and colleagues, 2009). In addition, brush force and technique have been examined. Mannerberg (1961) suggested that horizontal brushing caused two to three times more wear than vertical brushing. His evidence was the result of examining scratches on replicas of teeth taken from 32 dental nurses. Fraleigh, Elhaney, and Heiser (1967) found that brush force does play a role; however, the forces applied during brushing vary to such a degree that defining a standard is meaningless in designing studies. It is clear to see that this is a complex multifactorial equation.

CERVICAL WEAR LESIONS

Cervical enamel wear is common; however, relatively few epidemiologic studies have distinguished between cervical enamel wear and tooth wear in general (Bartlett and Shah, 2006). Most studies report general levels of tooth wear and do not comment on cervical wear as a separate entity. Cervical wear has a high prevalence, with reports between 5% and 85% in the adult population (Bartlett and Shah, 2006; Piotrowski, Gillette, and Hancock, 2001; Bergström and Lavstedt, 1979). While tooth wear is very common, the prevalence of severe dentin exposure on cervical sites is only 2% to 4%

(Bartlett and colleagues, 1998; Dugmore and Rock, 2004a; 2004b Bardsley, Taylor, and Milosevic, 2004).

Cervical wear lesions were first described by Pindborg in 1970 as the pathologic wearing away of substance by the friction of a foreign body independent of occlusion. He went on to describe these lesions as exhibiting a hard, smooth, highly polished surface, pink, firm marginal gingiva, and present in areas displaying adequate hygiene. The belief that cervical lesions were caused solely by overzealous tooth brushing has been a common theory amongst dental practitioners dating back to the early 18^{th} century. Pierre Fauchard suggested that toothbrushes were so rough and destructive to the teeth that he advocated the use of wet sponges instead (Sangnes, 1976). Today, however, there is a subscription to the philosophy that the lesions described by Pindborg have multiple etiologies (Addy and Hunter, 2003; Addy and Newcombe, 2005; Grippo, 1992; Grippo, Simring, and Coleman, 2012; Sangnes, 1976). Cervical tooth wear has been attributed to mechanical stress, attrition, erosion, and abrasion. However, there is still much debate over the relative contribution of each process to the etiology of cervical wear. More recent research has focused on the combined role of erosion and abrasion (Barlett and Shah, 2006). Studies have reported an acceleration of abrasion with acid-softening dissolution (Davis and Winter, 1980; Hooper and colleagues, 2003). Hooper and colleagues (2003) compared the effects of acid erosion and toothpaste abrasiveness on dentin and enamel *in situ*. They found that drinking orange juice instead of water prior to brushing significantly increased the abrasion of dentin; however, on enamel there was a similar trend toward increased abrasion, but statistical significance was not reached.

Multifactorial etiologies have been proposed in the literature, notably with Grippo and Masi (1991) describing "biodental engineering factors," such as the magnitude, duration and direction of masticatory forces, which contributed to corrosion at the cervical area. Davis and Winter (1980), as previously discussed, were the first to describe the acid-softening dissolution of enamel and dentin causing acceleration in abrasive wear. Eisenburger, Shellis, and Addy (2003) confirmed these findings, reporting evidence that both erosion and abrasion contribute to the development of wedge-shaped lesions. Their study simulated toothbrushing after an acidic challenge. Enamel loss was significantly greater when erosive and abrasive effects were combined. They concluded that acid-softened enamel is highly unstable and easily removed when abraded, and abrasion combined with erosion demonstrated a 50% increase in wear over erosion alone.

A more recent study by Hooper and colleagues (2003) examined the interplay between erosion and abrasion of enamel and dentin. In this *in situ* study, 15 volunteers wore acrylic appliances holding polished enamel and dentin sections 8 hours a day for 10 days. The volunteers drank 250 ml of orange juice or water over the course of 10 minutes, at four intervals throughout the day; after they drank, they brushed each specimen for 1 minute using a commercially available fluoride containing toothpaste. Using profilometry and measuring mass loss, the authors found that acid exposure increased the susceptibility of enamel to toothpaste abrasion. In addition, the amount of dentin loss correlated with the toothpaste abrasivity (RDA value). Litonjua, Andreana, and Cohen (2005) concluded after a review of six epidemiologic surveys that it has not been irrefutably established that any single factor is the main cause of non-carious

cervical lesions. Rather, they suggested that a number of factors, including toothpaste abrasion, dental erosion, and occlusal loading, may work in conjunction to produce these lesions.

Recent literature has focused on the accuracy of the term “erosion” to describe the loss of enamel and dentin by the actions of acids unrelated to bacterial origin. The term “erosion” has been called into question because it does not recognize proteolysis and piezoelectric effects. Grippo, Simring and Coleman (2012) proposed “biocorrosion” as a more accurate term because it takes these factors into account. They defined biocorrosion as degradation caused by chemical, biochemical and electrochemical means. They also described a model of pathodynamic mechanisms of tooth surface lesions. The model involves three components (stress, friction, and biocorrosion) that can be combined in any way to produce loss of tooth structure.

RESTORATION OF CERVICAL LESIONS

The decision to restore a non-carious cervical lesion is based on many factors, including prevention of pulpal involvement and consequent endodontic treatment, prevention of tooth fracture, and improvement in esthetic appearance. In addition, if the lesion has sharp edges, it can irritate the surrounding soft tissues. Another benefit of restoration is the elimination of a challenging area for the patient and hygienist to clean. These areas involve the dentin, accumulate calculus, and are often sensitive (Grippo, 1992). Grippo further suggested that if the complex etiology of these lesions is not addressed, it is better to abrade restorative material rather than have continued loss of tooth structure.

Restoration of the non-carious cervical lesion is accomplished in the same manner as the restoration of a carious cervical or Class V lesion. The outline of the cavity preparation is determined by the extent of the lesion; in general, bonded restorative materials require less mechanical retention within the preparation than non-bonded materials (Starr, 2001; Roberson, Heymann, Ritter, and Pereira, 2006). Practitioners may choose from a variety of direct restorative materials, including amalgam, direct gold, resin composite, glass ionomer, resin-modified glass ionomer, and polyacid-modified resin composite (Barnes, Blank, Gingell, and Gilner 1995; Abdalla and Alhadainy, 1997; Folwaczny and colleagues, 2001; Ermis, 2002).

RESTORATIVE MATERIAL WEAR

Many variables can influence the extent and rate at which polymeric composites wear. These can be extrinsic such as occlusion, mastication, toothbrushing, or parafunction activities, or they can be intrinsic to the restorative material itself. These intrinsic properties include the properties of the filler, the matrix, and the interface; the hardness of the filler relative to that of the abrasive; the content, shape, size, orientation, and distribution of filler; the relative wear resistance of filler to that of matrix; the relative abrasiveness of filler against the matrix; and the loading conditions during abrasive wear (Turssi, Purquerio, and Serra, 2003; Khamverdi, Kasraie, Rezaei-Soufi, and Jebeli, 2010; Geitel and colleagues, 2004).

Material Properties. In general, filler particle size and filler loading are the most significant factors in determining the wear resistance of resin composites. Hybrid resin composites possess filler particles ranging from 0.04 µm to 5 µm (mean ≈ 1µm) and filler loading of approximately 70% by volume. Microfilled resin composites range from 0.01

to 0.1μm (mean < 0.04 μm) in filler particle size and possess filler loading of less than 60% by volume (Roberson and colleagues, 2006). Nanofilled resin composites contain nanomeric (0.005 μm) particles as inorganic fillers. These filler particles are smaller than those found in typical microfilled and hybrid composites, and they allow for polish retention on par with microfilled composites, while maintaining the physical and mechanical properties of hybrids (Mitra, Wu, and Holmes, 2003).

Glass ionomers consist of an ion-leachable aluminosilicate glass and a liquid component of copolymers of acrylic acid. The material sets via an acid-base reaction with chelation of exposed calcium on the tooth surface to the material. This allows for direct bonding to the tooth structure. In addition, there is a slow release of fluoride, which is thought to be beneficial in high caries risk patients (Powers and Sakaguchi, 2006).

Resin-modified glass ionomers are also recommended in patients who are at high caries risk. These materials contain a powder that is similar to that of the traditional glass ionomer; however, the liquid contains resin monomers, polyacids, and water. Resin-modified glass ionomers set via an acid-base reaction, as well as light-cured polymerization of 2-hydroxyethyl methacrylate (HEMA). These materials will also bond to tooth structure like the traditional glass ionomers (Powers and Sakaguchi, 2006).

A giomer is a product created by Shofu Dental Corporation (San Marcos, CA). “Giomer” refers to any product that contains Shofu’s proprietary Surface Pre-Reacted Glass (S-PRG) filler particles (Shofu, 2011). Giomers have a typical resin composite composition in that they have an inorganic filler particle and organic resin matrix; however, they incorporate the pre-reacted glass ionomer particles into the filler. This

allows for mechanical properties of a resin composite with the fluoride releasing potential of a glass ionomer (Sunico, Shinkai, and Katoh, 2005). There are currently three giomer-based restorative materials commercially available in the U.S. – Beautifil® II, Beautifil® Flow, and Beautifil® Flow Plus (Shofu, San Marcos, CA)

Abrasive Wear. Tribology is a branch of mechanical engineering that studies the science of interacting surfaces in relative motion; it includes the study and application of the principles of friction, lubrication, and wear (Bhusan, 2001). Turssi, Purquerio, and Serra (2003) described a tribological system for wear of dental composites consisting of three basic elements: the structure (the types of materials in contact and the contact geometry), the interaction conditions (the loads, stresses, and duration of interaction), and the environment and surface conditions (the surface environment and chemistry, surface topography, and ambient temperature). They described the abrasive wear in occlusal contact-free areas, such as Class V restorations, as three-body abrasion or wear. In three-body abrasion, the presence of particles between or embedded in one or both of the two surfaces in relative motion causes material detachment (Dwyer-Joyce, Sayles, and Ioannides, 1994). This can be due to mastication with food or toothbrushing with an abrasive, in which the three bodies are the restorative material, toothbrush filament, and toothpaste abrasive. Abrasive wear increases when the abrasive particles' hardness increases relative to the hardness of the restorative material (Bhusan, 2001; Khamverdi and colleagues, 2010; Turssi, Purquerio, and Serra, 2003).

To better understand the interactions between toothbrush and toothpaste particles during the cleaning process, Lewis and Dwyer-Joyce (2006) conducted a simulation of abrasive tooth cleaning using water/glycerol mix on a polymethlmethacrylate (PMMA)

surface. They found that incorporating abrasives into a water/glycerol mix increased the coefficient of friction between the toothbrush and the PMMA; however, an increase in the concentration of abrasive particles did not increase the friction that much further. They concluded that only a few particles carry any load and, therefore, only a few particles are responsible for abrasion. They also performed abrasive scratch tests on acrylic to evaluate the interaction between the abrasive particles and the toothbrush filaments pushing them into the acrylic. They found that, again, only a few particles and filaments were involved in producing the scratches; however, once the filament changed direction, the particle was lost and a new particle was captured under the filament. It is important to note the clinical relevance: because the surface hardness of acrylic is similar to that of dentin, dentin abrasion during toothbrushing may occur in much the same manner.

Several studies have examined the effects of toothbrush abrasion on restorative materials that are employed in restoring carious and non-carious cervical lesions. An *in vitro* study by de Moraes and colleagues (2008) compared packable, microhybrid, nanohybrid, and microfilled resin composites. Material specimens were prepared in cylindrical molds and had baseline weight and surface roughness readings completed, then subjected to a brushing machine using a soft toothbrush for 60,000 strokes at 4 Hz with a brush load of 200 g. After the brushing cycle, the specimens were again weighed and had surface roughness measured. The materials with the larger filler particles (i.e., packable and microhybrid resins) had significantly greater weight loss than those with finer particles (microfilled and nanofilled resins). This was attributed to the debonding of the resin-filler interface causing some particles to be lost. Similarly, although all

materials exhibited comparable baseline surface roughness, the packable resin composite showed the roughest surface after toothbrushing. The authors concluded that the loss of particles resulted in not only weight loss, but an increase in surface roughening; nanohybrid and microfilled composites withstood the forces of toothbrushing better than packable and microhybrid composites.

Another *in vitro* study (Prakki and colleagues, 2007) evaluated the weight and surface roughness of three resin cements, one indirect resin composite, and one porcelain following toothbrushing abrasion. Following baseline weight and surface roughness measurements, the materials were subjected to a toothbrush abrasion simulation (soft brush; 300 g load; 100,000 strokes; new toothbrush at 50,000 strokes). All of the materials exhibited statistically significant weight loss and increased surface roughness after the abrasion challenge; the resin cement with the smallest sized filler particles had the smallest weight loss and maintained the smoothest surface of all the materials evaluated; the cement with the largest filler size showed the greatest degree of roughness. The porcelain exhibited the lowest weight loss and became smoother after abrasion.

Attin, Buchalla, Trett, and Hellwig (1998) examined toothbrushing abrasion of two polyacid-modified resin composites in both neutral and acidic buffer solutions. Twenty specimens of each material were soaked in either a neutral (pH = 6.8) or an acidic (pH = 3.0) solution, then brushed using an automatic toothbrushing machine (medium bristle toothbrush; 8,000 strokes; load = 275 g). Surface abrasion was evaluated using laser profilometry. Each material demonstrated a statistically significant decrease in abrasion resistance after acid storage.

Similarly, Garcia and colleagues (2004) compared the abrasion resistance of five flowable resin composites to a microhybrid and a microfilled resin composite. Following baseline measurements of mass and surface roughness (Ra values), 12 specimens of each material were subjected to a mechanical toothbrushing machine (100,000 strokes; load = 200 g) using a slurry prepared from a commercial dentifrice. All materials exhibited significantly greater surface roughness following the toothbrushing challenge, and all exhibited mass loss ranging from 1.29% to 3.77%. The flowable resins showed similar performance when compared to the microhybrid and microfilled resins; there were no statistically significant differences in either mass loss or surface roughness among the materials. Interestingly, the authors reported no correlation between surface wear and roughness for any of the materials.

Goldstein and Lerner (1991) examined toothbrushing abrasion on the surface of a hybrid composite resin. A concern they had that led to this study was the attraction of dental plaque to roughened restorations. They suggested that the mass loss was not of clinical significance, but the greater focus should be on the surface roughness that is produced. They examined the surface roughness, as measured by profilometry, of a hybrid composite before and after brushing (brushing machine; 20,000 strokes) with eight different commercially available toothpastes. Brushing with deionized water had no effect on the surface of the material; however, all specimens showed a worsening of the surface smoothness when brushed with each dentifrice. Furthermore, there were statistically significant differences in surface texture amongst the toothpastes, with Colgate toothpaste producing less roughness than the other dentifrices.

RESTORATIVE MATERIAL SURFACE ROUGHNESS

Effects on Soft Tissues. The studies cited above show that restorative materials incur a measurable amount of mass loss with toothbrushing. Moreover, they also highlight that toothbrushing abrasion yields a significantly rougher material surface. This rougher surface is of concern because it can retain dental plaque (Quirynen and Bollen, 1995). The adherent bacteria are of even greater concern due to the location of the Class V lesions often approximating the gingival tissues. This may lead to increased attachment loss, a specific concern if a restoration has already been placed due to exposed dentinal tissues. Larato (1972) observed signs of gingivitis adjacent to subgingival Class V conventional resin composite restorations with rough surfaces, while the adjacent gingival tissue on unrestored enamel surfaces was healthy.

A review by van Dijken and Sjöström (1995) found that, with well-polished restorations, there was no increase in the degree of gingivitis; however, significantly higher crevicular fluid levels were associated with resin composite restorations than with enamel (i.e., unrestored teeth). This may be an indication of a subclinical reaction to the restorative materials or to undetectable differences in plaque retention. In addition, the studies that found no differences in degree of gingivitis did not conduct long-term analyses for changes in surface texture and possible effects on the gingival tissues. Van Dijken, Sjöström, and Wing (1987) found a greater degree of plaque and gingival inflammation on three- to four-year-old resin composite restorations compared to one-year old restorations. In addition, bacterial recolonization of the older restorations was significantly faster than for enamel surfaces. The faster recolonization may indicate a higher risk for periodontal disease in an already susceptible population. These studies

suggest that despite polishing and acceptable surface smoothness upon initial placement, over time, increasing surface roughness may lead to an increase in gingival inflammation.

Effects on Plaque. A more recent study by Paolantonia and colleagues (2004) compared the short-term clinical and microbiological effects in the gingival tissue following the completion of various subgingival restorations. The 16 subjects enrolled in the study needed cervical restorations in three adjacent teeth. Each patient had his teeth restored with one of each of the following restorative materials: amalgam, glass ionomer cement, and resin composite. Subgingival plaque samples were collected from the mid-buccal aspect of each experimental tooth and one adjacent non-treated tooth every four months for one year. There was no significant change in the subgingival microflora over time among teeth restored with amalgam or glass ionomer, or among non-restored teeth; however, the teeth restored with resin composite showed significant increases in total bacterial counts and significant increases in gram negative anaerobic bacteria. The authors speculated that the surface deterioration that occurs in resin composite with *in vivo* wear leads to increased plaque accumulation. A limitation of this study is that the restorations were evaluated for only up to one year. A longer-term study may have shown that the other restorative materials eventually accumulated bacterial levels comparable to those of resin composite.

Glass ionomer cements have also been examined for their plaque and bacterial adhesion. A common belief is that fluoride-leaching materials may interfere with surface colonization by cariogenic bacteria such as mutans streptococci. Hallgren, Oliveby, and Twetman (1992) reported a lower proportion of *Streptococcus mutans* adjacent to orthodontic brackets retained with a glass ionomer cement, as compared to brackets

retained with a resin composite during 28 days of appliance wear. Berg, Farrell, and Brown (1990) compared bacterial levels around Class II glass ionomer and resin composite restorations and similar caries-free sites in 15 patients. One week after placement, the glass ionomer restorations exhibited lower *S. mutans* levels than the caries-free surfaces. However, at one and three months after restoration placement, the restored and caries-free surfaces displayed no statistically significant differences in *S. mutans* levels. This suggests that the initial high release of fluoride from glass ionomer restorations may inhibit microbial attachment to the restoration; however, as the amount of fluoride that is released decreases, so does its effect on cariogenic bacteria.

CLINICAL PERFORMANCE OF RESTORATIVE MATERIALS

Barnes and colleagues (1995) compared a polyacid-modified resin composite (PAMRC) to a conventional light-cured resin-based composite (RBC) in non-carious Class V lesions (n = 68 PAMRC, 32 RBC). After 12 months, the restorations were compared on retention, color match, post-operative sensitivity, and marginal adaptation. Each material exhibited retention of over 96%, with no statistically significant differences between the materials in any category. The authors reported that both materials provided acceptable clinical results.

Abdalla, Alhadainy, and Garcia-Godoy (1997) examined the clinical performance of three resin-modified glass ionomers and one polyacid-modified resin composite in Class V carious lesions over two years. They selected a total of 40 patients with 80 Class V lesions; 20 restorations of each material were placed. The restorations were evaluated after one and two years using US Public Health Service (USPHS) criteria. All restorative materials tested were clinically acceptable when evaluated on color, form,

marginal adaptation, and cavosurface discoloration. There were no statistically significant differences among materials for any property, except color stability, for which the polyacid-modified resin was superior to the resin-modified glass ionomers.

Folwaczny and colleagues (2001) compared the clinical performance of four restorative materials (two different resin-modified glass ionomer cements, a resin composite, and a polyacid-modified resin composite) in Class V lesions over three years. One restoration was placed in each of 197 patients. The restorations were evaluated after three years for shade match, surface texture, marginal integrity, marginal discoloration, and anatomic contours using USPHS criteria. They found no statistically significant differences in restoration retention among the four materials; however, based on overall performance, the best material was the resin composite, and the poorest was the resin-modified glass ionomer.

Ermis (2002) conducted a two-year study to compare the clinical performance of four polyacid-modified resin composites and a resin-modified glass ionomer in Class V lesions. A total of 20 restorations of each material were placed in 30 patients. Two calibrated clinicians who were blinded to material selection evaluated the restorations at baseline, and again at six, 12, and 24 months for retention, color match, cavosurface marginal discoloration, anatomic form, marginal adaptation, secondary caries, and postoperative sensitivity. All of the restorations were clinically acceptable, with no statistically significant differences among the materials after two years for any of the criteria measured.

Loguercio, Reis, Barbosa, and Roulet (2003) conducted a five-year study examining a resin-modified glass ionomer and a polyacid-modified resin composite used

to restore non-carious cervical lesions. This was an *in vivo* study using 12 patients having at least one pair of equal-sized non-carious cervical lesions. A total of 32 restorations were placed, half with each restorative material. They assessed the restorations at placement for a baseline, and again at five years for retention, anatomical form, marginal adaptation, marginal discoloration, color match, surface texture, and secondary caries. After five years, 28 restorations (14 of each material) were available for evaluation. The authors concluded that the resin-modified glass ionomer was significantly better in terms of marginal discoloration, retention, and marginal adaptation. However, the polyacid-modified resin was found to be better in surface texture and color match. In addition, they found no secondary caries with either material.

A study by Geitel and colleagues (2004) evaluated one hybrid and two microfilled resin composites in Class III, IV, and V restorations. Using a split-mouth design, 134 patients with comparably sized caries lesions in homologous tooth pairs received restorations with two different restorative materials. The restorations were evaluated after two years for marginal integrity, anatomic form, secondary caries, color, marginal discoloration, and surface roughness. The authors concluded that the hybrid resin composite was significantly superior to both of the microfilled materials when assessed based on color, marginal integrity, and marginal discoloration; however, when compared based on anatomic form, secondary caries, and surface roughness, there were no significant differences among the three materials.

Turkun and Celik (2008) evaluated the performance of a polyacid-modified resin composite and a nanofilled resin composite in restoring non-carious Class V lesions. They enrolled 24 patients, with a total of 100 restorations. All restorations were

evaluated at baseline and again at six, 12 and 24 months for color match, marginal discoloration, marginal adaptation, secondary caries formation, anatomic form, postoperative sensitivity, surface roughness, and retention. The nanofilled resin composite restorations had a 100% retention rate, which was statistically significantly higher than that of the polyacid-modified resin (96%); however, the polyacid-modified resin restorations exhibited significantly better color match. The authors concluded that both restorative materials demonstrated clinically acceptable performance in Class V non-carious lesions.

As the previous studies have shown, a variety of materials are clinically acceptable to use in the restoration of Class V lesions. Hybrid, microfilled, and nanofilled resin composites, as well as resin-modified glass ionomers and polyacid-modified resins, have all been shown to yield satisfactory results. However, as newer materials are developed and introduced to the market, there is a need to evaluate them compared to the already available materials. One such newer material being giomers.

A 2011 study by Jyothi and colleagues evaluated a resin-modified glass ionomer and a giomer. Forty Class V restorations of each material were placed in 32 patients and evaluated at 15 days, six months, and one year. At one year, neither the giomer nor the resin-modified glass ionomer exhibited surface staining, marginal discoloration, or postoperative sensitivity; however, the giomer had superior surface finish. The authors concluded that both the giomer and resin-modified glass ionomer showed clinically acceptable performance after one year; however, longer term studies are needed to gain a better understanding of these materials.

WHITENING TOOTHPASTES

Esthetics is a large part of dentistry, and there is a growing demand among consumers for tooth whitening products (Joiner and colleagues, 2005; Alkhatib, Holt, and Bedi, 2004, 2005; Xiao and colleagues, 2007). To satisfy this demand, companies market toothpastes as "whitening." To achieve the "whitening" claim, manufacturers employ one of two strategies: bleaching the teeth (i.e., lightening the intrinsic pigmentation within the tooth structure), or removing extrinsic stains from the tooth surface. Most whitening toothpastes aim to remove extrinsic stain; the primary stain removal ingredient is the abrasive (Khamverdi and colleagues, 2010; Joiner, 2007, 2010). Joiner (2010) examined the abrasives commonly used in whitening toothpastes. He acknowledged that manufacturers try to optimize stain removal effectiveness, while limiting abrasive damage to tooth structure and restorative materials. To achieve their goals, manufacturers employ combinations of abrasives (Nathoo and colleagues, 2008; Sreenivasan and colleagues, 2009).

Abrasive wear. Turssi, Faraoni, Rodrigues, and Serra (2004) compared the abrasive effects of a whitening dentifrice and a regular dentifrice using an *in situ* model. Fourteen volunteers wore removable appliances containing three enamel and three dentin slabs on each side. They were randomly assigned to use either a regular toothpaste or a whitening toothpaste. Twice daily during the three-day experimental period, the appliances were removed and one side immersed in a sugar-free soft drink (pH = 3.1) for 90 seconds, while the other side was unexposed. The enamel and dentin slabs were then brushed in the same manner with either the regular or whitening toothpaste and examined for wear using a profilometer. Compared to the regular toothpaste, the whitening

toothpaste caused significantly greater wear on sound enamel and on both acid-challenged and sound dentin; however, there was no significant difference in abrasion between the two dentifrices on acid-challenged enamel. The authors suggested this might be due to the acid softening the most superficial part of the enamel sufficiently that even the less abrasive toothpaste removed it.

Vicentini, Braga, and Sobral (2007) examined the *in vitro* effects of toothbrushing with nine toothpastes on dentin wear. Bovine dentin blocks were subjected to 10,000 strokes on a toothbrush simulator using a 200 g load. The specimens were then examined for weight loss and surface roughness using a profilometer. The three toothpastes marketed to lighten teeth caused the greatest dentin wear; these products all contained calcium carbonate as a common abrasive. In contrast, toothpastes containing silica removed the least dentin. The authors further suggested that, while chemically identical, abrasives may have differing effects when in mixtures compared to when used individually.

Joiner and colleagues (2005) used an *in situ* model with *ex vivo* brushing to examine dentin wear caused by two toothpastes, one standard and one whitening. Each study participant (n = 25) wore a removable appliance with enamel and dentin slabs affixed to it. The specimens were brushed for 30 seconds twice daily for 12 weeks. Participants were instructed to wear their appliances continually for 24 hours and not use any other toothpaste, mouthwash, or denture cleaner for the duration of the study. There was no statistically significant difference in dentin wear rates between the standard and whitening toothpastes. The enamel specimens showed a significant difference in wear only at the eight-week mark, with the standard toothpaste causing more wear; at 12

weeks, enamel wear was the same for both toothpastes. The authors concluded that the wear of dentin is not linear, and that the greatest wear occurs in the first four weeks.

Microhardness. Whitening toothpastes have been assessed for more than just wear potential. Khamverdi and colleagues (2010) examined the *in vitro* microhardness of enamel and a microhybrid composite resin when brushed with a whitening toothpaste. After four weeks of brushing twice a day for one minute each time, the whitening toothpaste had no effect on the surface hardness of enamel, but caused a significant decrease in the hardness of the restorative material.

SUMMARY

It is clearly a concern that abrasives found in toothpastes, both traditional and whitening, contribute to cervical wear. The zealous patient is likely to be interested in the appearance of his teeth and may over-use a whitening dentifrice to achieve his goals. In addition, both the prevalence and severity of gingival recession increase with age, leading to exposure of a greater number of at-risk cervical and root surfaces. As a result, with an aging population, we are likely to see an increase in the incidence of cervical and root caries (Shay, 1997; Beltran-Aguilar and colleagues, 2005; Walls and Meurman, 2012). The combination of more Class V lesions and increased use of whitening toothpaste could lead to a surge in long-term negative outcomes.

Several studies have examined the effects of dentifrice abrasion on the various materials used in the restoration of cervical lesions. In addition, several studies have evaluated the abrasivity of whitening toothpastes. With the possible increasing prevalence of cervical lesions, as well as the increasing use of whitening toothpastes, it is important to better understand the effects of dentifrices on the restorative materials used

to treat these lesions. Class V cervical lesions are commonly restored with direct placement of esthetic (tooth-colored) restorative materials. Due to their location near the gingiva, increased surface roughness may contribute to bacterial adherence and, thus, gingival irritation and recession. Daily use of whitening toothpastes may abrade and further roughen the surfaces of certain restorative materials. Hence, it is important to determine (1) if the whitening toothpastes that are commonly used today roughen the surfaces of Class V restorative materials, and (2) if these materials differ in their resistance to abrasion from brushing with various dentifrices. Therefore, the purpose of this investigation is to determine the effects of a standard and a whitening dentifrice on the surface roughness and abrasion resistance of four esthetic restorative materials that are commonly used to treat cervical lesions.

CHAPTER II: MATERIALS AND METHODS

This *in vitro* repeated measures design quantified and compared the effects of prolonged abrasion by two dentifrices on the mass of four commonly used restorative materials. The independent variables were: (1) restorative material (four levels [resin composite, glass ionomer, resin-modified glass ionomer, giomer]); and (2) dentifrice (three levels [standard dentifrice, whitening dentifrice, and deionized water]) applied over four time intervals (0 [baseline], 50,000, 100,000, and 150,000 toothbrushing cycles). The dependent, or outcome, variable was specimen mass, measured before and after each 50,000 toothbrushing cycles. In addition, representative specimens were evaluated microscopically (600X) at each interval to assess surface topography.

We chose four categories of direct esthetic restorative materials commonly used for Class V lesions: resin composite; glass ionomer; resin-modified glass ionomer; and giomer. The materials used in this study are outlined in Table 1 (following page).

SAMPLE SIZE DETERMINATION

Using a sample size calculator developed by the University of British Columbia Department of Statistics (http://www.stat.ubc.ca/~rollin/stats/ssize/n2.html), with the following assumptions:

α (Type I error):	0.05
Sigma (common S.D.):	15% of the mean
Power:	0.80
Two-sided Test	

the sample sized needed to detect a 20% difference between mean values was calculated to be n = 9.

Table 1. Restorative materials evaluated.

Material	Manufacturer	Composition
Resin Composite (Filtek Supreme Ultra)	3M ESPE St. Paul, MN, USA	Bis-GMA, UDMA, TEGDMA, and bis-EMA (4-20nm, 72.5% by weight
Glass Ionomer (Fuji IX)	GC America Inc, Alsip, IL, USA	Powder: Alumino-fluoro-silicate glass (95%), polyacrylic acid powder (5%) Liquid: deionized water (50%), polyacrylic acid (40%), polybasic carboxylic acid (10%)
Resin-modified Glass Ionomer (Fuji II LC)	GC America Inc, Alsip, IL, USA	Powder: Alumino-fluoro-silicate glass (amorphous) (95-100%) Liquid: polyacrylic acid (20-25%), 2-HEMA (30-35%), Proprietary ingredient (5-10%), 2,2,4, Trimethyl hexamethylene dicarbonate (1-5%)
Giomer (Beautifil II)	Shofu Kyoto, Japan	Bis-GMA (7.5%), Triethyleneglycol dimethacrylate (<5%), Aluminofluoro-borosilicate glass (70%), Aluminum Oxide, DL-Camphorquinone, Others

SPECIMEN PREPARATION

Twenty-seven specimens of each material were fabricated using a silicone mold (5 mm diameter x 3mm thickness) to ensure uniform dimensions. After the material was inserted into the mold, the surface was covered with a polyester matrix strip and slightly pressed using a glass microscope slide. Specimens were cured according to manufacturers' recommendations. Materials requiring visible-light cure were cured for (60 seconds) through the strip with an LED visible-light curing (VLC) unit (Demi Plus, Kerr Sybron Dental Specialties, Middleton, WI, USA). After curing one side, the

specimen was removed and the opposite side was cured for 60 seconds as well. Self-curing materials were allowed to set for 10 minutes prior to removal from the silicone molds.

Following storage in deionized water for 4 days, the specimens were hand-polished with wet 240-, 320-, 400-, and 600-grit silicon carbide abrasive paper (CarbiMet 2, Buehler, Lake Bluff, IL, USA) on a water-cooled polishing table (HandiMet 2, Buehler). The specimens were stored in deionized water for 60 days before baseline weight measurement.

BASELINE WEIGHT MEASUREMENT

The initial weight measurements were made using an electronic analytical balance (Mettler AE240, Columbus, OH, USA) with 0.0001 g accuracy. Each specimen was blotted dry with absorbent paper to remove excess water. The materials were stored for 60 days before initial measurements were taken in order to ensure the materials weight stabilized.

INTERMEDIATE AND FINAL WEIGHT MEASUREMENTS

The mass of each specimen was measured after 50,000, 100,000, and 150,000 strokes, following the same procedures used for baseline measurements.

SURFACE TOPOGRAPHY ASSESSMENT

Surface topography was evaluated qualitatively using a digital microscope (Hirox K-7700, Hirox-USA, Hackensack, NJ) at 600X. A mounting jig was fabricated to ensure that all specimens were positioned identically for imaging. Three representative

specimens from each material-abrasive treatment group were viewed at baseline and after 50,000, 100,000, and 150,000 brushing strokes.

TOOTHBRUSH ABRASION TEST

All specimens were subjected to toothbrushing abrasion performed with an automatic toothbrushing simulation apparatus (Toothbrush Simulator SM-3, SD Mechatronik, Munich, Germany) (Appendix B). The machine holds 12 soft nylon bristled toothbrush heads under a 200 g load in a perpendicular direction to the sliding surface. Each specimen received a total of 150,000 brush strokes (100 strokes/min; 8 mm stroke travel distance). At each 50,000-stroke interval (8.5 hours of continuous brushing), specimens were removed for weight measurements and representative samples for surface imaging. Toothbrushes were replaced after each 50,000 strokes.

Specimens were brushed with either a regular or a whitening dentifrice (Colgate Total or Colgate Sparkling White, Colgate-Palmolive Company, New York, NY). Slurry was prepared using a 3:1 ratio (by weight) of deionized water to dentifrice. Approximately 15 mL of slurry was placed in each well until specimen was covered in slurry. Wells were cleaned and new slurry added at each 50,000 stroke interval. A control group (n = 9) was brushed for 150,000 strokes in exactly the same manner, but with deionized water rather than dentifrice.

STATISTICAL ANALYSIS

Mean (± standard deviation) mass values were calculated at baseline and after 50,000, 100,000, and 150,000 strokes for each of the three dental materials subjected to each abrasive medium (standard dentifrice; whitening dentifrice; deionized water –

control), Mean values were compared via a two-factor Mixed Design (between – within subjects) analysis of variance (ANOVA) and, where indicated, Tukey HSD post hoc tests. The independent variables were: 1) dental material [four types] and 2) abrasive medium [repeated measures, with three conditions (standard dentifrice; whitening dentifrice; water – control) applied over four time intervals (baseline, 50,000, 100,000, and 150,000 strokes). Statistical analyses were accomplished using Statistical Package for the Social Sciences (SPSS) Version 18 computer software (SPSS, Inc., Chicago, IL). All significance levels were set at $\alpha = 0.05$.

CHAPTER III: RESULTS

Results are displayed in Figures 1 – 3. In general, all materials showed a slight, but statistically significant, mass loss when brushed for 150,000 strokes in each dentifrice, as well as deionized water. Mass loss tended to be linear over each 50,000-stroke interval. For deionized water (Figure 1), the glass ionomer (Fuji IX) demonstrated the least resistance to mass loss. However, all materials showed a statistically significant mass loss (all $p < 0.04$).

Figure 1. Restorative material abrasive mass loss over 150,000 brushing cycles. Abrasive medium = deionized water (control) (n = 9).

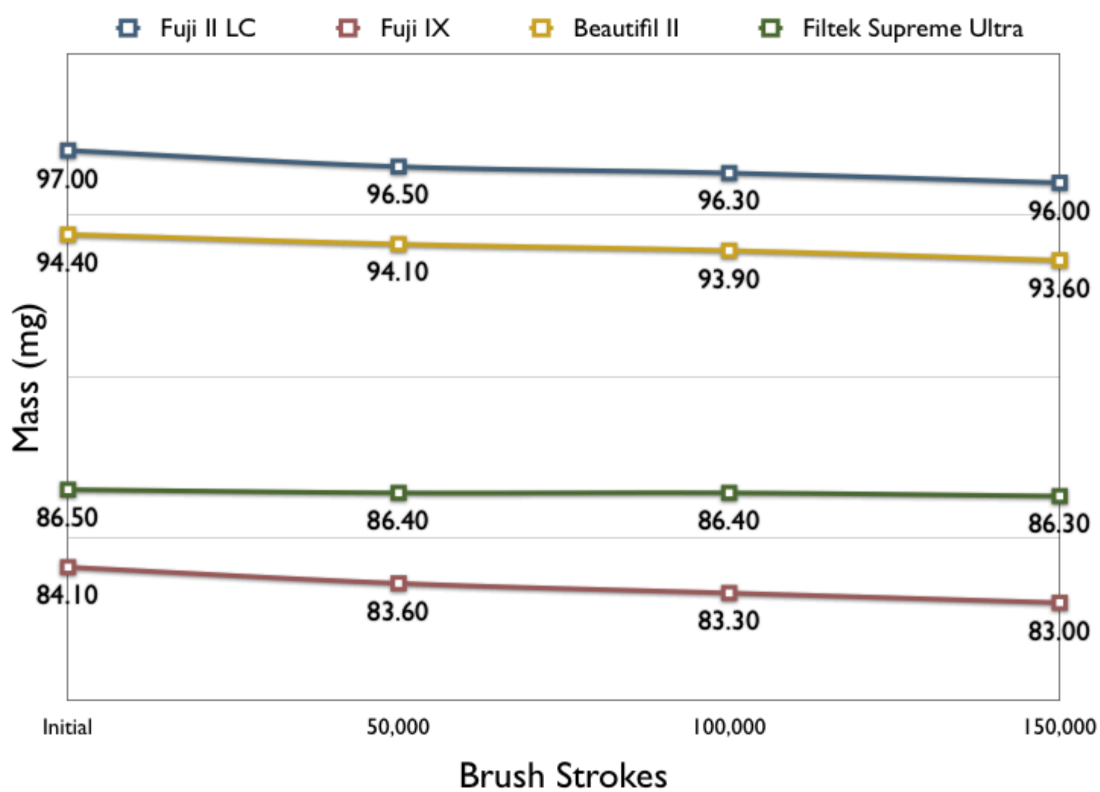


Figure 2 shows the materials brushed with a regular dentifrice (Colgate Total).

There is a slight, but statistically significant mass loss over time ($p < 0.035$).

Figure 2. Restorative material abrasive mass loss over 150,000 brushing cycles. Abrasive medium = regular dentifrice (Colgate Total) (n = 9).

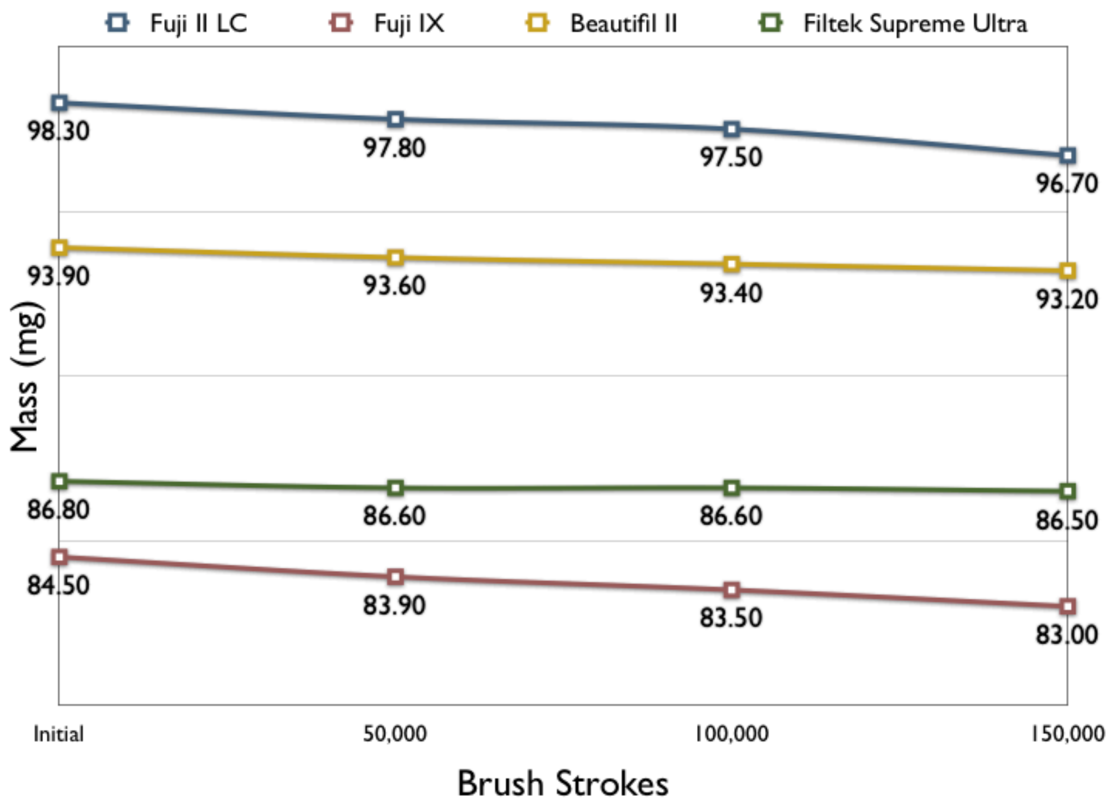
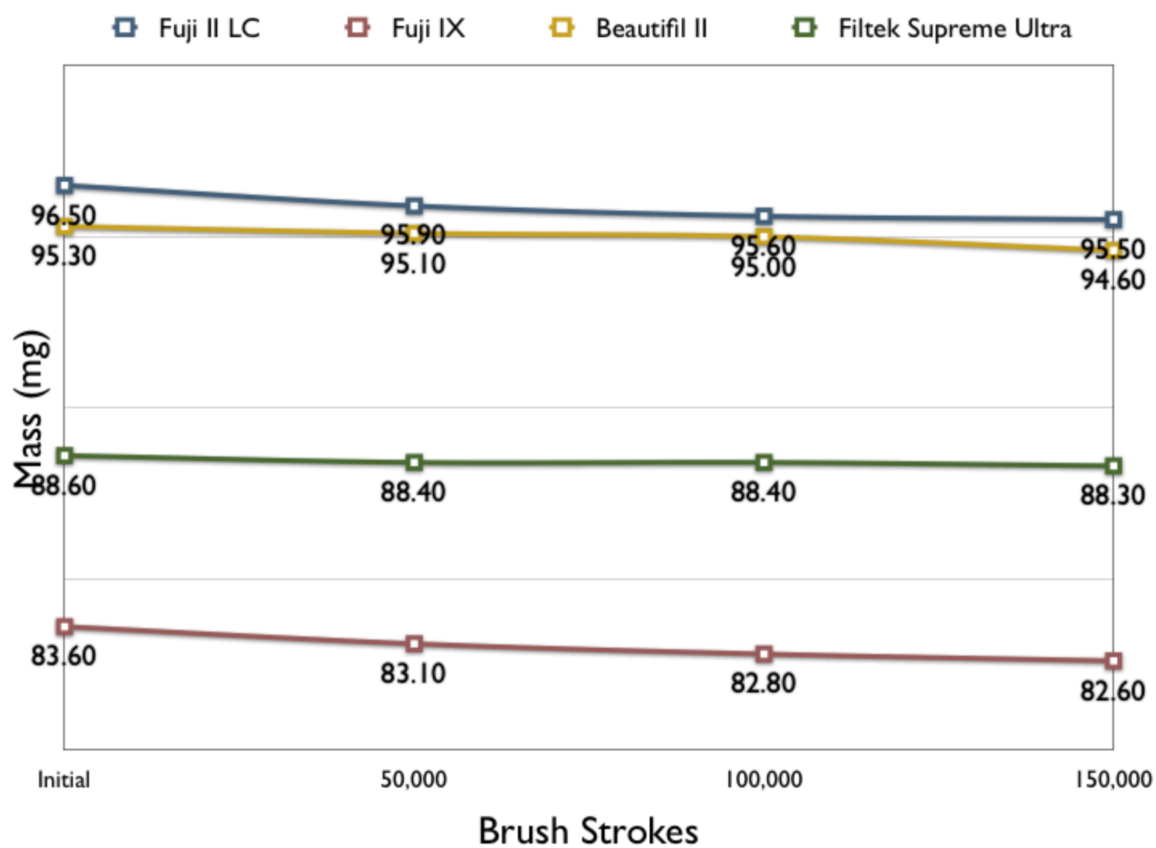


Figure 3 depicts the mass loss of each material when brushed with a whitening dentifrice (Colgate Whitening). As with the regular dentifrice and the control, each material experienced a statistically significant mass loss over 150,000 cycles (all $p < 0.002$).

Figure 3. Restorative material abrasive mass loss over 150,000 brushing cycles. Abrasive medium = whitening dentifrice (Colgate Whitening) ($n = 9$).



For each material, there was no significant difference in mass loss between the standard and whitening dentifrices (all $p > 0.$). Neither dentifrice was significantly different from deionized water ($p > 0.225$).

Table 2 shows the percent total mass loss from baseline through 150,000 brushing cycles for each restorative material in each abrasive medium. The greatest mass loss occurred with the glass ionomer (Fuji IX) when brushed with the standard dentifrice (Colgate Total) (1.78%). The least mass loss occurred with the resin composite (Filtek Supreme Ultra) when brushed with deionized water (0.23%). For each abrasive medium, and for all three media combined, the order of mass loss was as follows: Filtek Supreme Ultra (0.31%) < Beautifil II (0.78%) < Fuji II LC (1.23%) < Fuji IX (1.43%).

Table 2. Percent mass loss from baseline through 150,000 brushing cycles by restorative material and abrasive medium.

Material	Deionized Water	Colgate Total	Colgate Whitening	Mean
Fuji II LC	1.03%	1.63%	1.04%	1.23%
Beautifil II	0.85%	0.75%	0.73%	0.78%
Filtek Supreme Ultra	0.23%	0.35%	0.34%	0.31%
Fuji IX	1.30%	1.78%	1.20%	1.43%

Table 3 shows the statistical significance groupings for mass loss by restorative material. Mass loss was significantly greater for the glass ionomer (Fuji IX) than for the resin (Filtek Supreme Ultra) and the giomer (Beautifil II). Mass loss was not significantly different for the resin, giomer and the resin-modified glass ionomer (Fuji II

LC). In addition, mass loss was not significantly different for the resin-modified glass ionomer and the glass ionomer.

Table 3. Mean mass loss (grams) by restorative material.*

Material	N	Subset	
		1	2
Filtek Supreme Ultra	27	.000137	
Beautifil II	27	.000354	
Fuji II LC	27	.000613	.000613
Fuji IX	27		.000874
Statistical Significance		.053	.489

* Repeated measures ANOVA and Tukey HSD post hoc tests ($\alpha = 0.05$).
Subsets 1 and 2 are statistically significantly different.
Groups within each Subset are not statistically significantly different.

Figures 4 – 7 show the images taken with the digital microscope at 600x magnification. For all of the materials, the surface topography appears relatively unchanged from baseline through 150,000 brushing cycles.

Figure 4. Surface topography of resin-modified glass ionomer (Fuji II LC) over 150,000 brushing cycles (600X magnification).

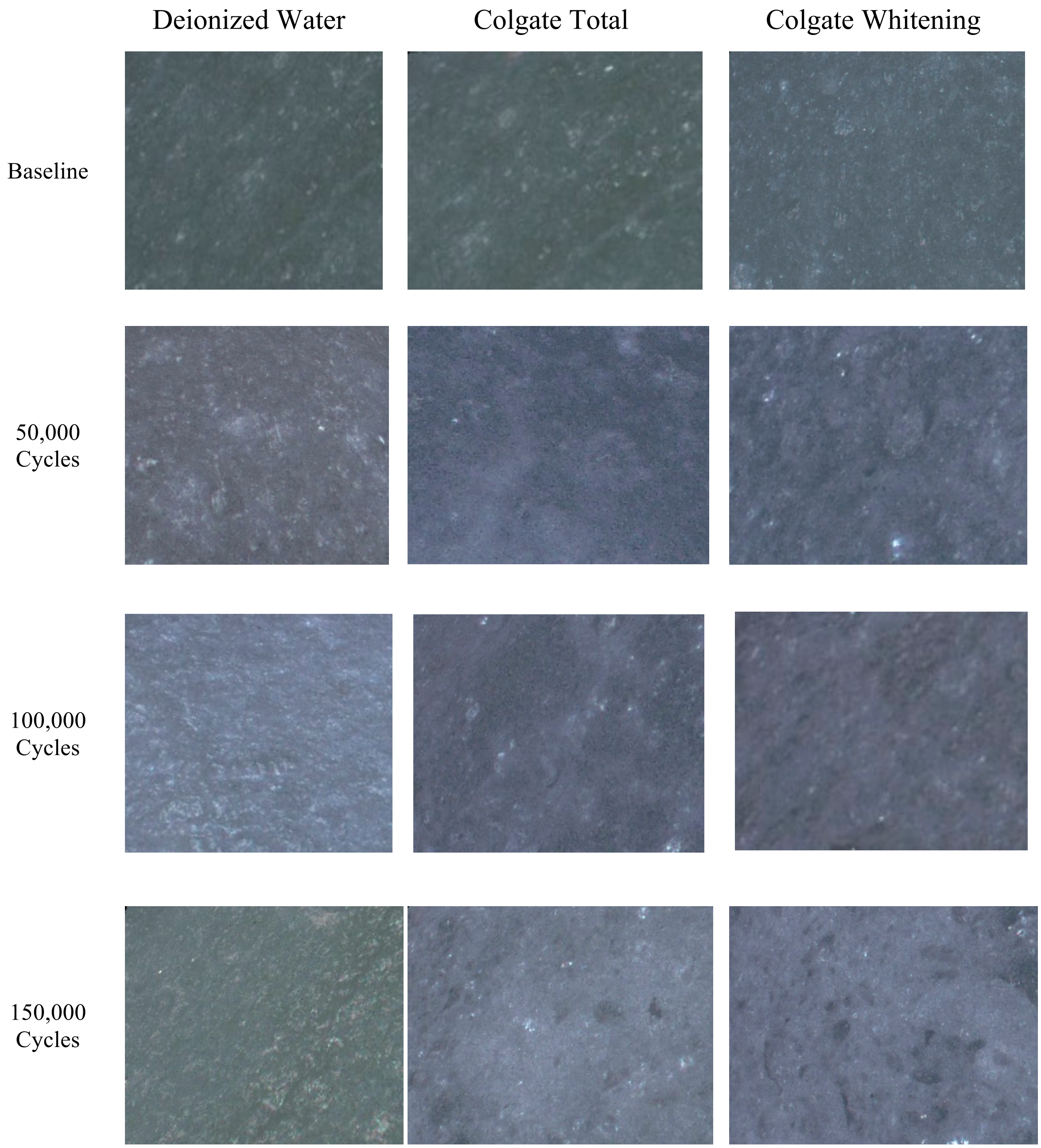


Figure 5. Surface topography of glass ionomer (Fuji IX) over 150,000 brushing cycles (600X magnification).

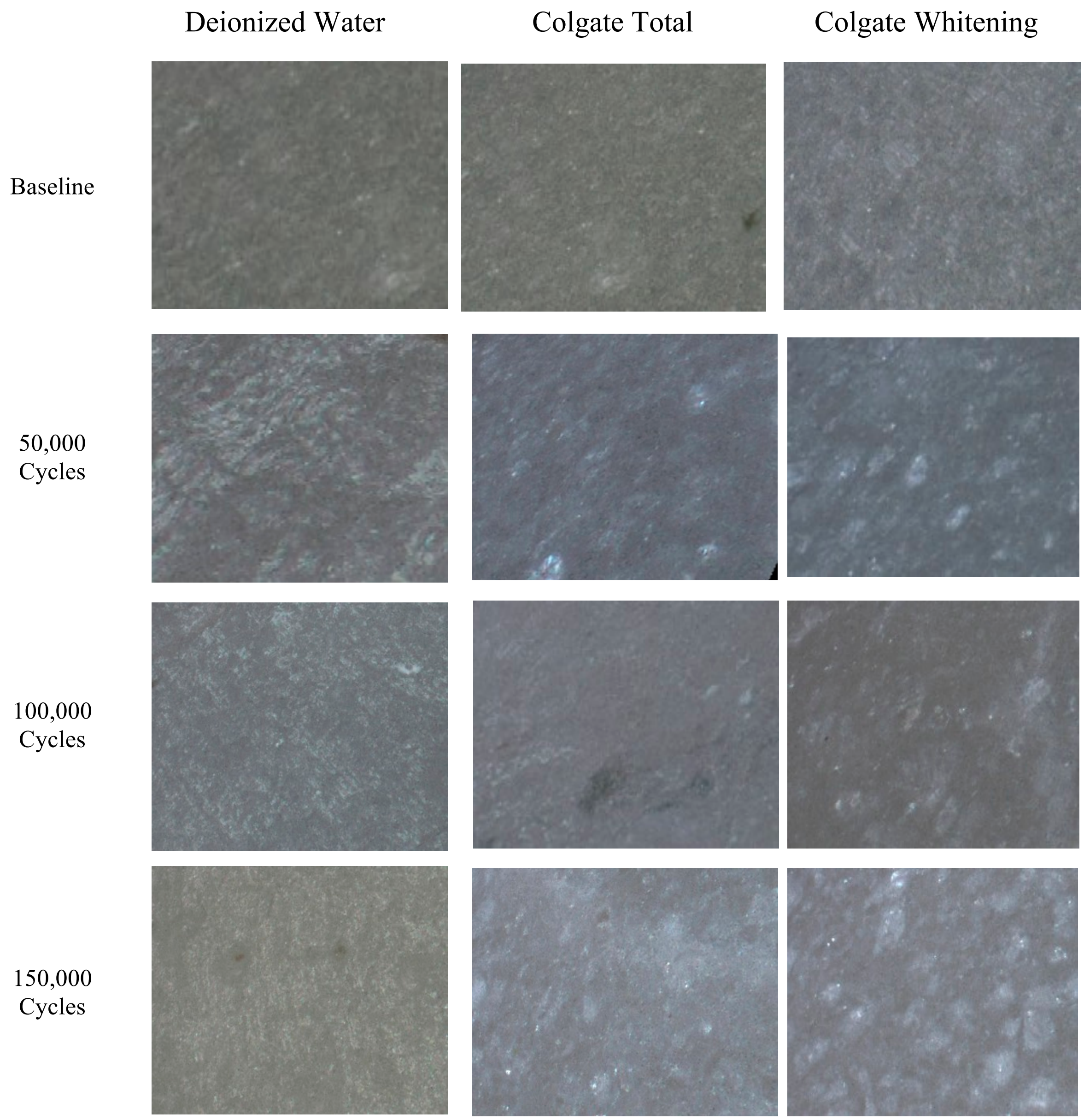


Figure 6. Surface topography of giomer (Beautifil II) over 150,000 brushing cycles (600X magnification).

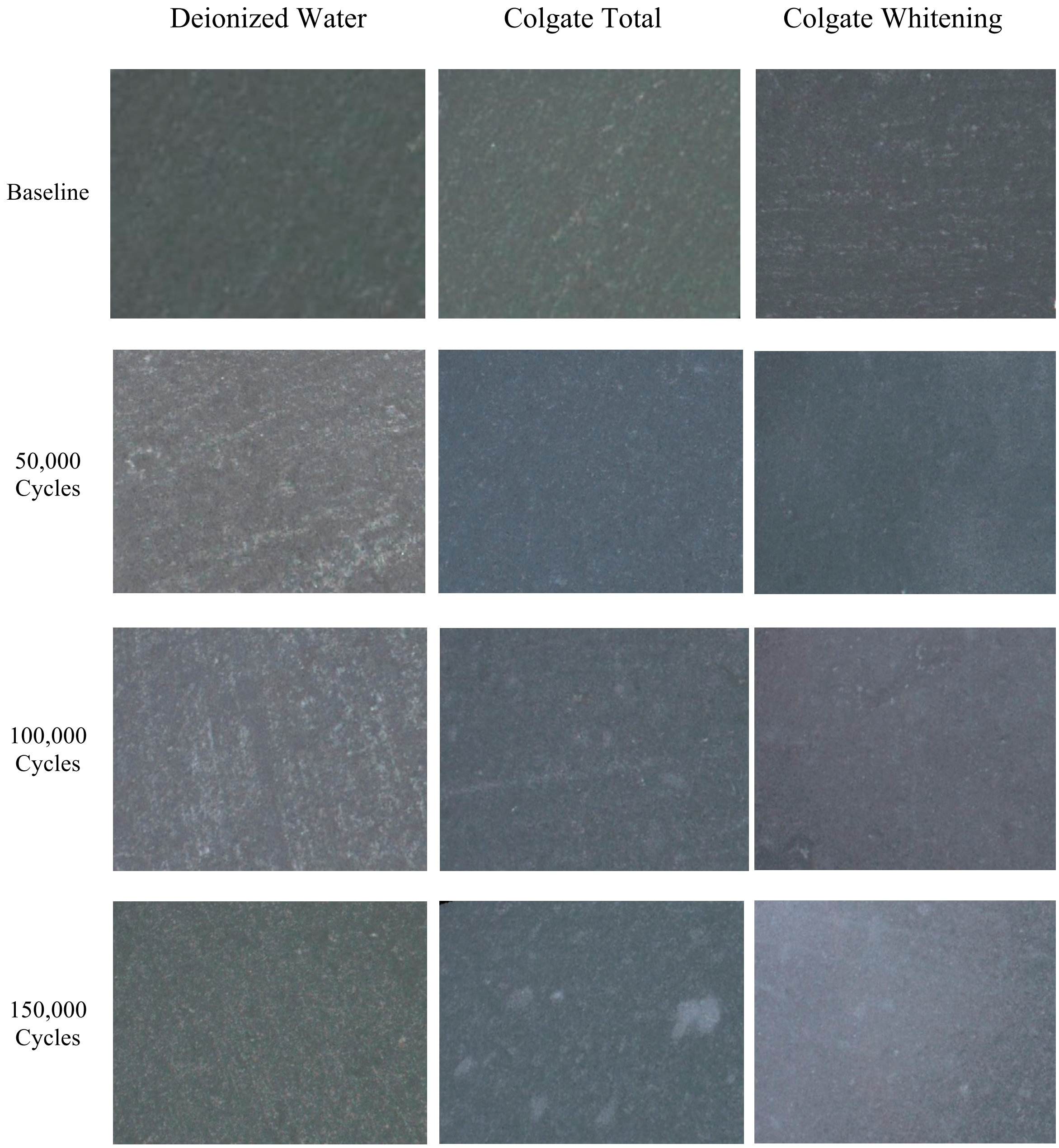
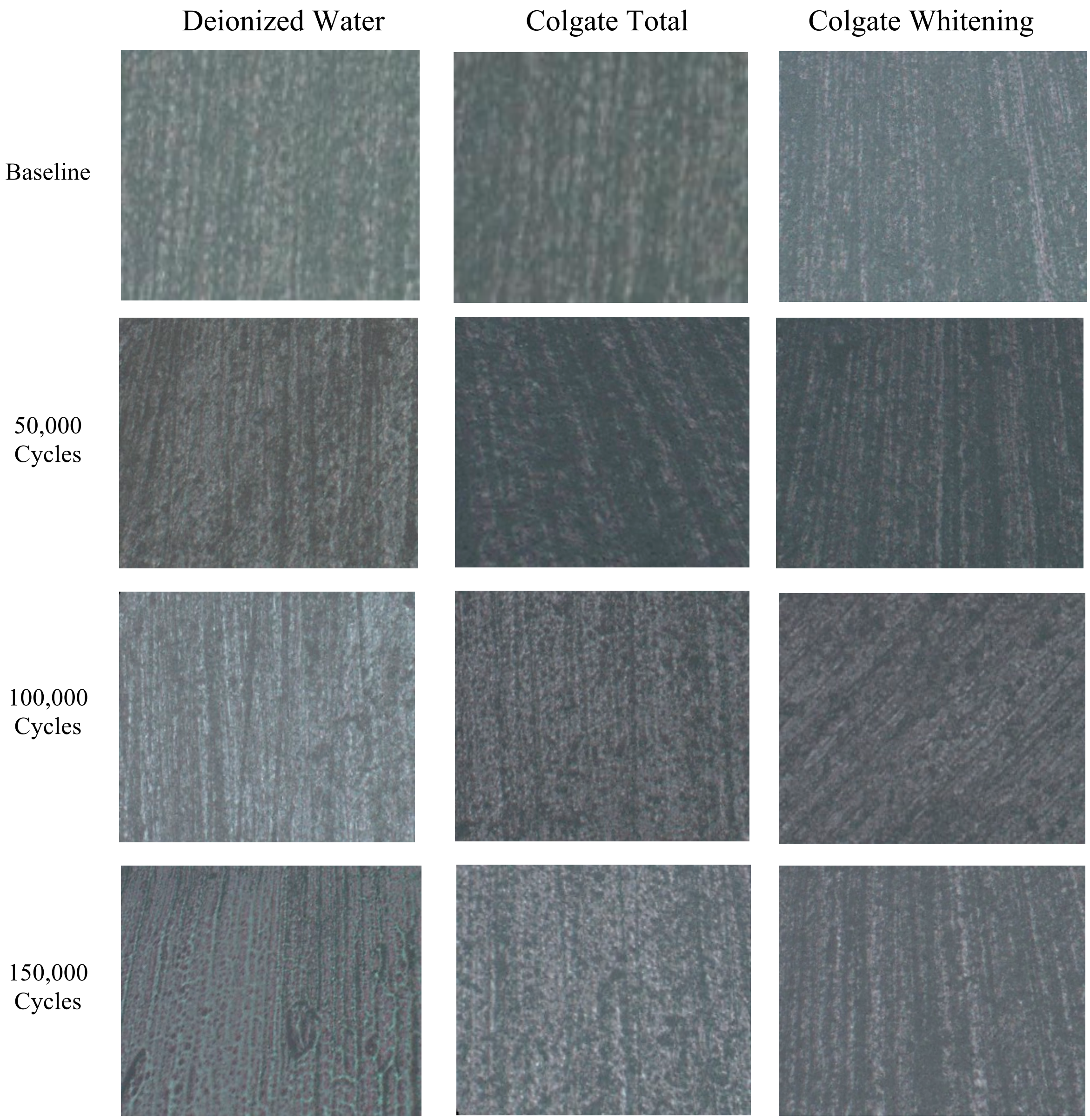


Figure 7. Surface topography of resin composite (Filtek Supreme Ultra) over 150,000 brushing cycles (600X magnification).



CHAPTER IV: DISCUSSION

This study sought to determine whether a whitening toothpaste abraded restorative materials to a greater extent than a regular toothpaste, as well as compare the surface roughness of the materials after brushing. Overall, there was a measurable, statistically significant, mass loss among all four restorative materials from baseline to final; however, the regular and whitening dentifrices produced no differences in material abrasion.

The results of our study agree with others that found a decrease in mass after brushing (Garcia and colleagues, 2004; Prakki and colleagues, 2007; Wang and colleagues, 2004). These studies evaluated a variety of materials (conventional, flowable, and pckable resin composites, porcelain); however, protocols for abrasion testing were similar. Most materials exhibited statistically significant differences in mass over the testing intervals.

Kawai and colleagues (1998) compared the effect of resin monomer composition on the toothbrushing wear resistance of resin composites. They found that for materials containing Bis-GMA, wear resistance increased with the more TEGDMA in the resin matrix. In our study, two materials, Filtek Supreme Ultra and Beautifil II, contain Bis-GMA resin matrices. Beautifil II does not contain any additional TEGDMA in its matrix; however, Filtek Supreme Ultra does.

A limitation of this study was the inability to quantify changes in surface roughness. The digital microscope uses a multifocal algorithm to derive the surface topography. The grooves observed in the images may have been beyond the resolution limit. Another possible explanation may be due to the translucent nature of the material

itself. The limitations of the digital microscope enabled only qualitative assessment of the specimen surfaces.

Johannsen and colleagues (2013) illustrated the importance of measuring toothpaste abrasivity in both a quantitative and qualitative way. They compared the abrasive effects of 12 toothpastes using acrylic plates in a toothbrushing machine. After brushing, they calculated surface roughness values, as well as volume loss. They concluded that the dentifrice RDA values had a very poor correlation to the resulting surface roughness values as well as volume loss. In addition, they found that some toothpastes resulted in higher mass loss, yet also a smoother surface.

In the absence of quantitative data, definitive comparisons of surface topography are difficult. Limited to qualitative discussion, our photographic images demonstrated no discernible differences among either the dentifrices or the materials. Yin and colleagues (2009) compared the effects of whitening toothpastes on the surface roughness of two resin composites and a giomer using a profilometer. They found no statistically significant difference between Colgate Total and Colgate Advanced Whitening for one of the resins and the giomer. However, a third toothpaste, Darlie All Shiny White, produced a significant increase in surface roughness among all three materials. These results suggest that Colgate Whitening may not be as abrasive as other types of whitening toothpastes.

Abrasive mass loss can be of clinical concern as dental tissues may become exposed and require replacement of the restoration. Among the materials in our study, the greatest relative mass loss occurred with the glass ionomer, Fuji IX, when brushed with the regular toothpaste. While this was the largest average percent loss at 1.78%, this

may be of little clinical significance, as it occurred over the course of 150,000 brushing cycles, or the estimated equivalent of 6.3 years of service (Wang and colleagues, 2004). Of greater relevance may be the relative order of wear resistance among the materials evaluated (resin composite > giomer > resin-modified glass ionomer > glass ionomer). This order appears to correlate with the relative resin content of the materials. Given a choice between "stronger" or "weaker," we would generally prefer the strongest, most durable material for every restoration. However, clinicians must weigh such potential shortcomings against known benefits when choosing restorative materials for specific situations.

CHAPTER V: CONCLUSIONS

Under the conditions of this *in vitro* study, standard and whitening dentifrices produced measureable and statistically significant abrasion among four direct esthetic restorative materials. There was no significant difference in abrasion, as measured by mass loss, between the two dentifrices, as well as deionized water; nor were there any qualitative changes in surface topography when viewed under magnification. The abrasion resistance appears to be clinically acceptable for all four restorative materials.

The relative order of wear resistance among the materials evaluated (resin composite > giomer > resin-modified glass ionomer > glass ionomer) correlated with the relative resin content of the materials. Although all materials lost mass over time, the small amount (0.23% to 1.78%) lost over an estimated equivalent of 6.3 years is likely not clinically significant. Therefore, patients should not be concerned with using either Colgate Total or Colgate Whitening for fear of abrading away their restorations. However, these results may not hold true for all whitening toothpastes.

APPENDIX A

Data Collection Sheet.

Material __________________

	Deionized Water (Control)					Standard Dentifrice					Whitening Dentifrice				
Specimen	Baseline	50K cycles	100K cycles	150K cycles	Total Mass loss	Baseline	50K cycles	100K cycles	150K cycles	Total Mass Loss	Baseline	50K cycles	100K cycles	150K cycles	Total Mass Loss
1															
2															
3															
4															
5															
6															
7															
8															
9															
10															
11															
12															

APPENDIX B

Toothbrushing Simulator Video

Provided by:

Ms. Nicole McFarland
Mr. Dean Giamette
Bureau of Medicine & Surgery
Visual Information Directorate
WRNMMC, Bethesda, MD

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